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(54) Method and control means for control of fuel injection system

(57) A method of determining a control parameter for a fuel injection system, in particular for a high-pressure fuel pump with an electrically actuable valve determining the quantity of fuel to be injected, wherein a dead time of the system is ascertained in certain operating states. For this purpose, the duration (ASDV) of a drive signal for a preliminary injection phase is modulated in time at defined frequency and amplitude and is increased starting from a low value range, at which preliminary injection does not occur. The increase is continued until occurrence of preliminary injection is recognised, with the aid of an output signal of a sensor detecting a magnitude, for instance detonation, influenced by injection.

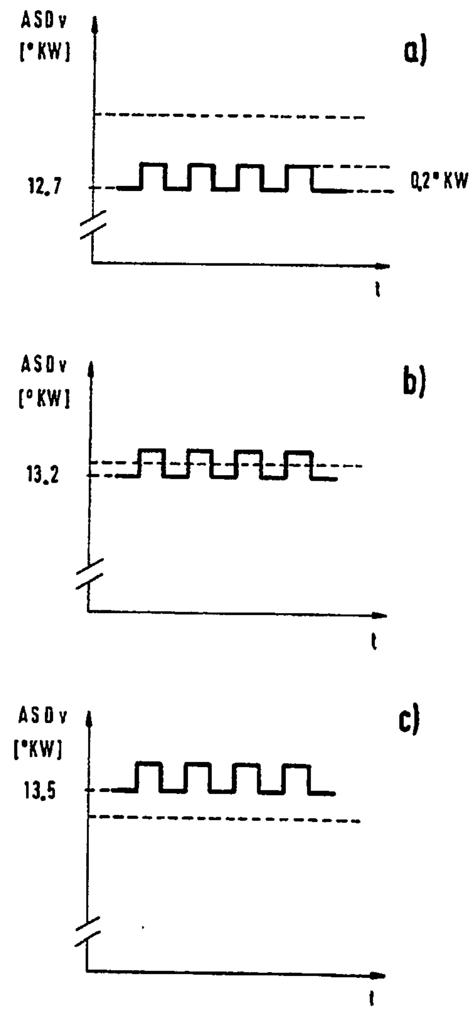

Fig.5

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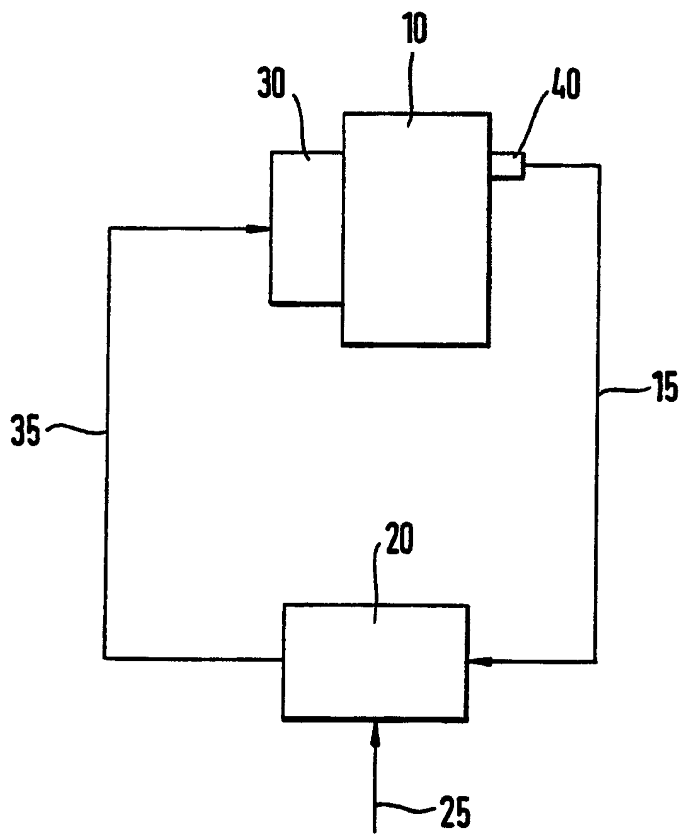

Fig.1

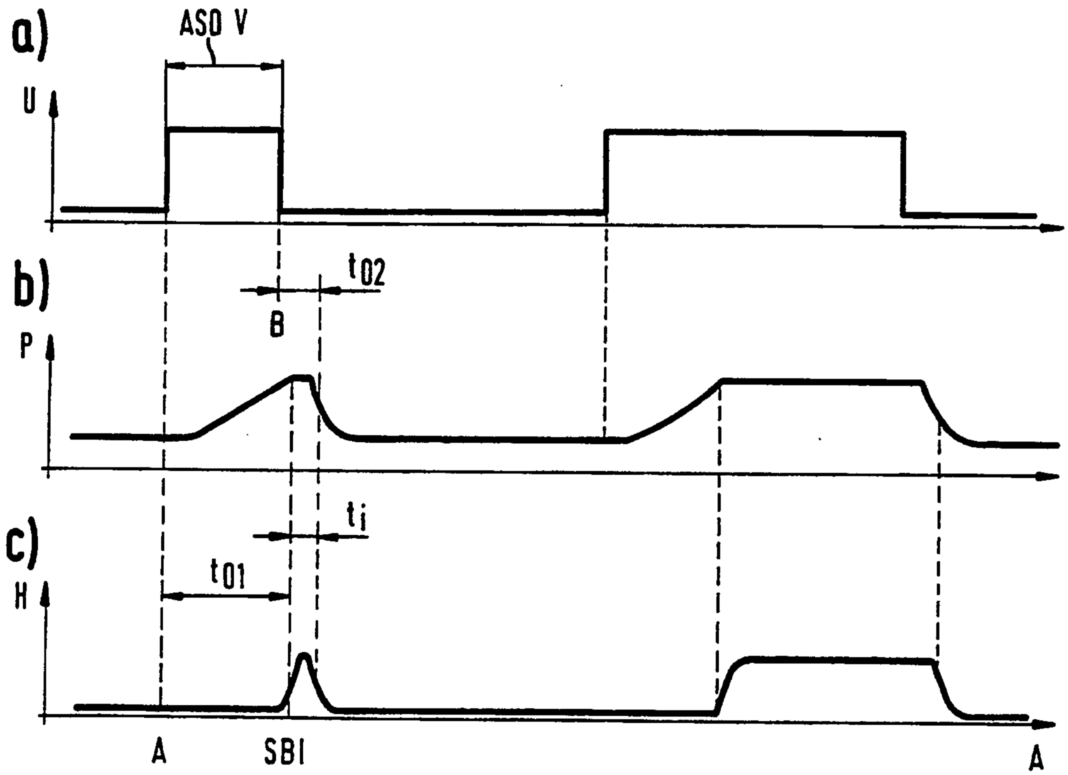

Fig. 2

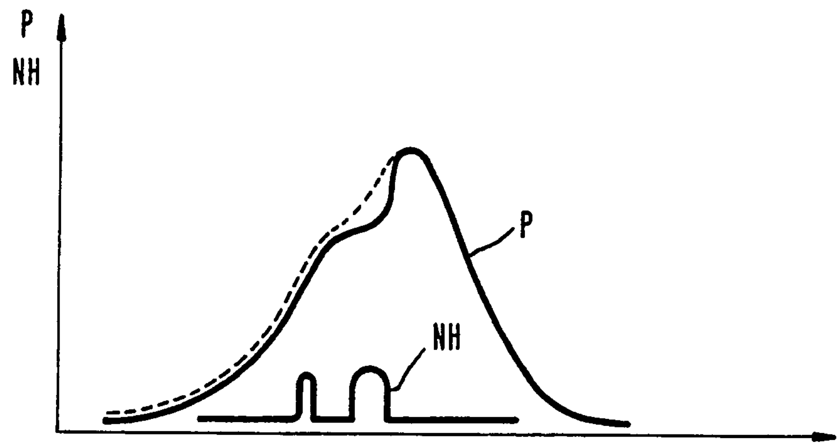

Fig.3

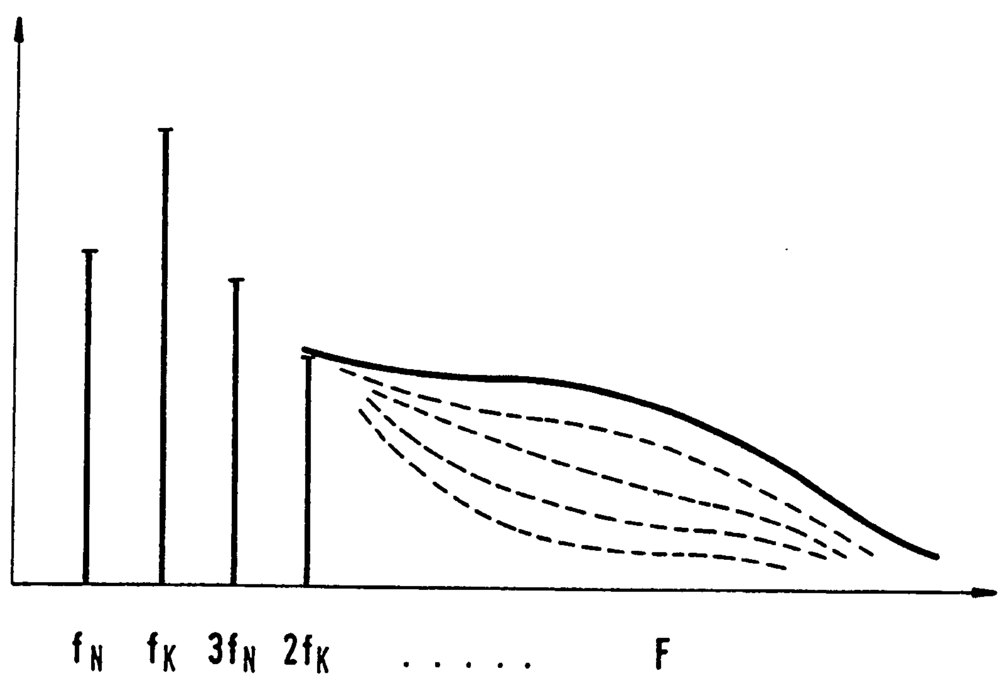

Fig.4

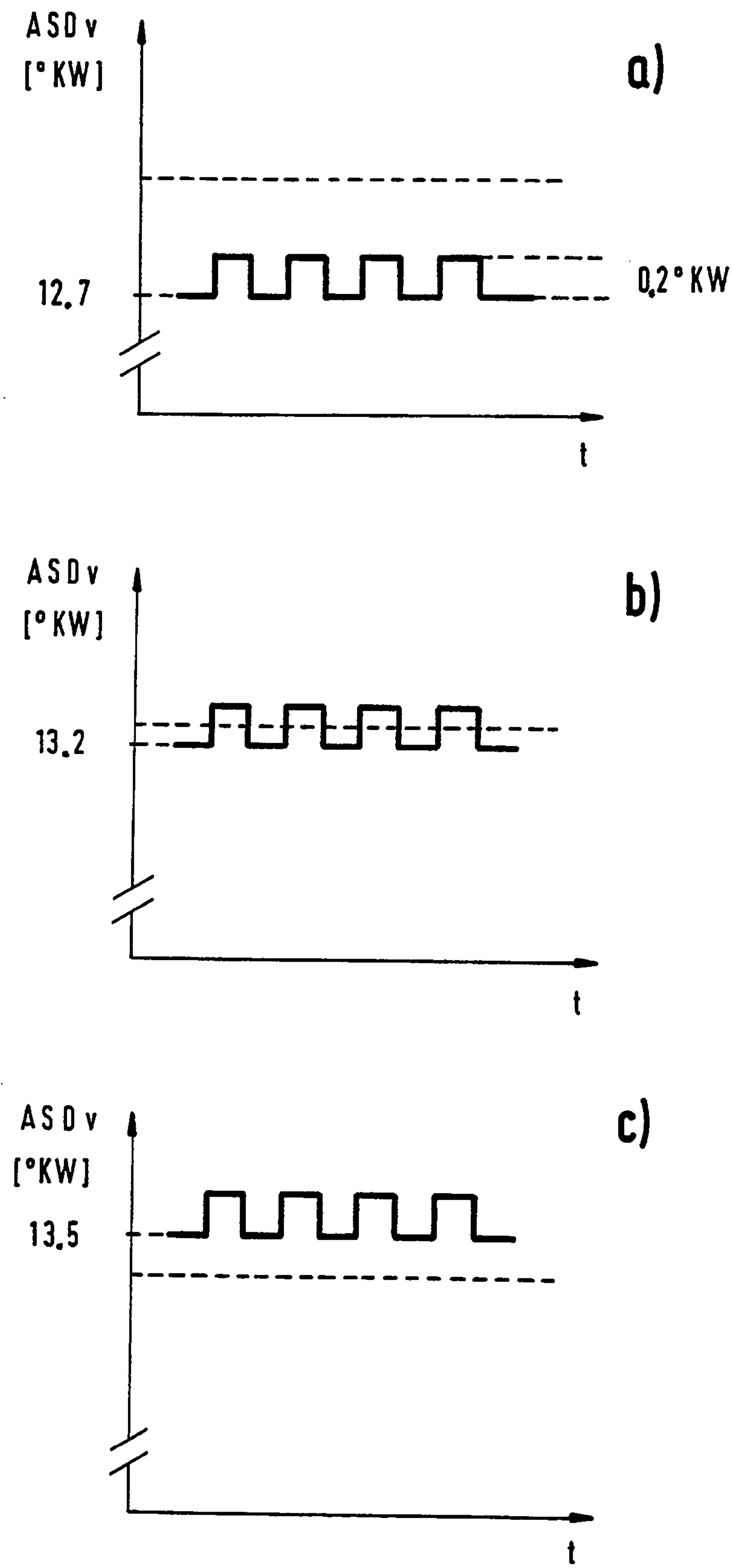

Fig.5

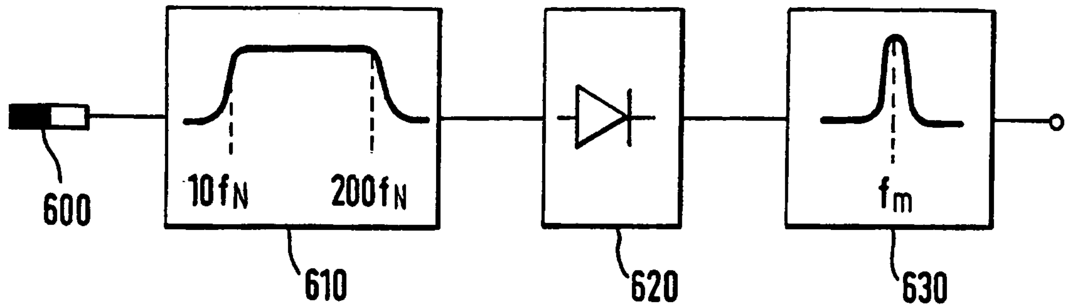
600
10fN
200fN
610
620
fm
630

Fig.6

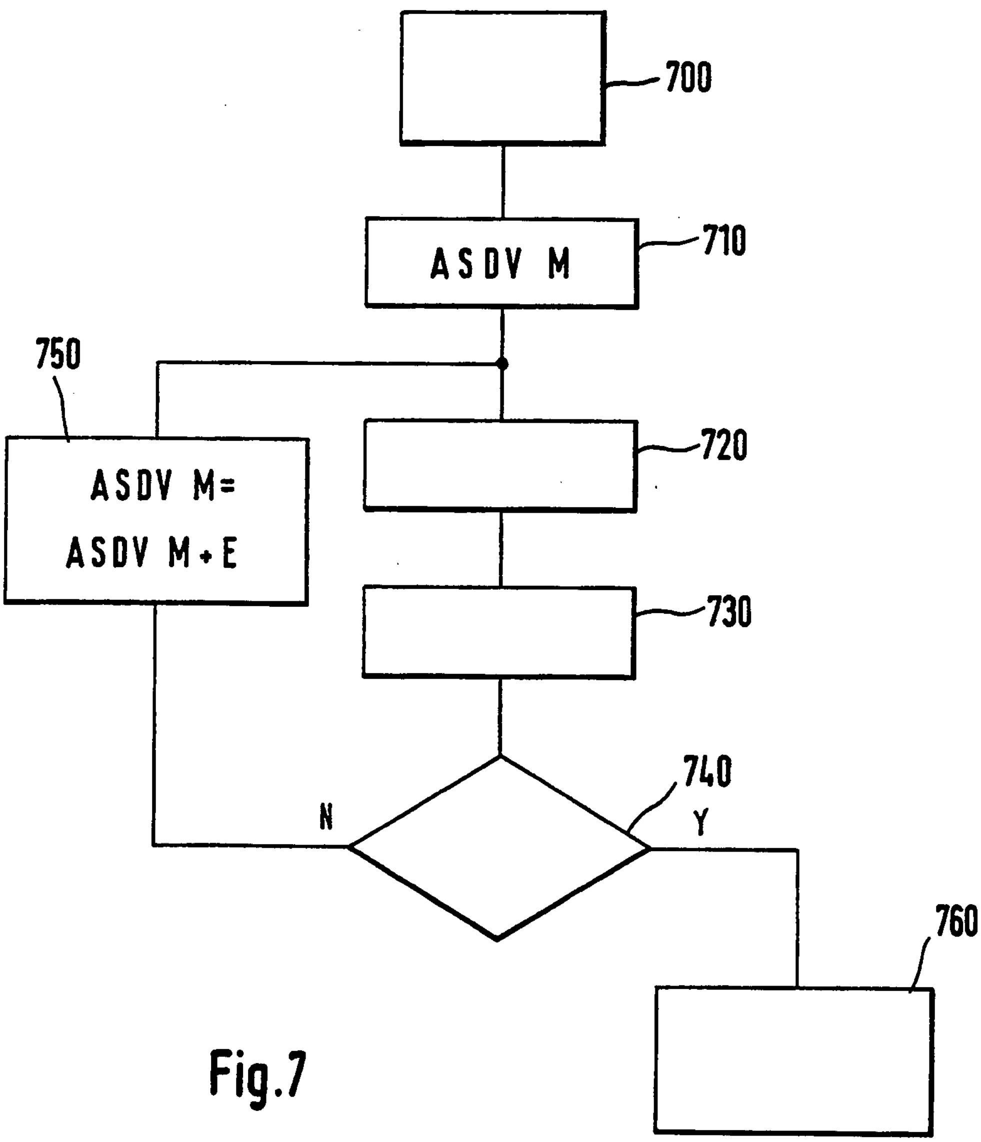
700
ASDV M
710
750
ASDV M=
ASDV M+E
720
730
740
N
Y
760

Fig.7

METHOD AND CONTROL MEANS FOR CONTROL OF FUEL INJECTION SYSTEM

The present invention relates to a method and control means for the control of a fuel injection system, in particular for determining a control parameter for the system.

In DE-OS 39 29 747 (US-A 5 070 836) there is disclosed a method for the control of a fuel injection system for a high-pressure fuel pump, in which at least one magnetic valve determines the quantity of fuel to be injected into an internal combustion engine. The drive control of the valve is effected in such a manner that a preliminary injection is performed first and then a main injection.

Due to production tolerances and ageing phenomena, there is a scatter in the quantity of fuel injected into the individual cylinders of the engine. This scatter has the effect that different quantities of fuel are delivered to the engine for the same drive signal during the preliminary injection.

Since only very small quantities are concerned in the case of the preliminary injection, the case can arise that no preliminary injection or a preliminary injection with too high a quantity takes place for the same drive signal. Consequently, the advantages of preliminary injection, in respect of combustion noise, are lost, i.e. combustion noise is again pronounced or soot emission is greatly increased. Since the scatter between the individual cylinders is substantial, the case can arise that a correct preliminary injection takes place for individual signals, but no preliminary injection, or one with an excessive quantity, takes place for others.

In order to compensate for this scatter, the particular duration of the valve drive pulse at which the onset of preliminary injection occurs is ascertained in certain operating states. Starting from this, compensating signals for drive signals which cause preliminary injection are formed and stored. For detection of the drive signal at which onset of injection occurs, the duration of the signal is increased starting from a value at which no preliminary injection occurs, until it is recognised, by way of a reporting signal, that a prelimimary injection has taken place.

This procedure has the disadvantage that the evaluated signal changes only very slightly on transition from absence to presence of preliminary injection. The ascertaining of the duration of the signal above which preliminary injection takes place is thus difficult.

It would thus be desirable, for the purpose of eliminating scatter in the injected quantity of fuel, to improve the sensitivity of such a method.

According to a first aspect of the present invention there is provided a method of determining a control parameter for a fuel injection system providing preliminary and main injection in an engine by way of an electrically actuable valve, the method comprising the steps of determining a dead time of the system by modulating the duration of a drive signal for the valve in time at a defined frequency and amplitude, increasing the duration starting from a value range too low for preliminary injection to occur, and detecting, on the basis of a sensor signal indicative of at least one magnitude influenced by injection, first occurrence of preliminary injection in response to the increase in the duration.

According to a second aspect of the invention there is provided control means for a fuel injection system providing preliminary and main injection in an engine by way of an electrically actuable valve, the control means comprising means for determining a dead time of the system by modulating the duration of a drive signal for the valve in time at a defined frequency and amplitude, increasing the duration starting from a value range too low for preliminary injection to occur, and detecting, on the basis of a sensor signal indicative of at least one magnitude influenced by injection, first occurrence of preliminary injection in response to the increase in the duration.

An example of the method and embodiment of the control means of the present invention will now be more particularly described with reference to the accompanying drawings, in which:

Fig. 1 is a block circuit diagram of an engine installation with control means for a fuel injection system thereof;

Figs. 2a to c are diagrams showing, respectively, valve drive signal pulses, fuel pressure and injection valve needle stroke;

Fig. 3 is a diagram showing the course of engine cylinder pressure and valve needle stroke as a function of time;

Fig. 4 is a diagram showing a frequency spectrum of cylinder pressure;

Fig. 5a to c are diagrams showing different valve drive signals;

Fig. 6 is a block diagram of signal evaluating means in control means embodying the invention; and

Fig. 7 is a flow chart illustrating steps of a method exemplifying the invention.

Referring now to the drawings there is shown in Fig. 1 the essential parts of a system for injection of fuel into an internal combustion engine and control means for the system. The engine 10 receives a certain quantity of fuel admetered by a fuel pump 30. Different sensors 40 detect measurement values 15, which characterise the operating state of the engine, and conduct these to a control device 20. The control device 20 computes, starting from the measurement values 15 and further magnitudes 25, drive-on pulses 35 acting on the fuel pump 30.

The engine is preferably a compression-ignition engine, and the fuel pump 30 comprises an electrically actuable valve. The beginning and the end of the fuel injection can be controlled by controlled driving of the valve, which can be, for example, piezo-electrically or magnetostrictively actuated. In the following, this electrically actuable valve is denoted as electromagnetic valve.

The control device 20 computes the quantity of fuel to be injected into the engine. This computation takes place in dependence on the different measurement values 15, such as rotational speed, engine temperature and actual start of injection, and optionally also on the further magnitudes 25, which characterise the operational state of the engine and/or of a vehicle fitted with the engine. These further magnitudes are, for example, the setting

of the accelerator pedal of the vehicle or ambient air pressure. The control device 20 converts the desired quantity of fuel into the drive pulses and a quantity-determining member of the fuel pump 30 is then acted on by these pulses. An electromagnetic valve, which is so arranged that the quantity of fuel to be injected is determined by the opening duration or closing duration of the electromagnetic valve, can serve as the quantity-determining member.

The electromagnetic valve is, for example, so arranged in the high-pressure fuel pump that pressure builds up in the element chamber of the pump after the closing of the valve during the conveying phase of the pump element and the injection takes place automatically when a certain pressure value is exceeded. After opening of the valve, the pressure in the chamber falls and the injection is terminated. A preliminary injection before the actual main injection can be achieved through brief closing and subsequent opening of the valve in the conveying phase of the pump element.

Preferably, a separate high-pressure fuel pump with an electromagnetic valve determining the quantity of fuel to be injected is provided for each cylinder of the engine. On the other hand, it is also feasible to provide a high-pressure fuel pump with an electromagnetic valve which then charges all cylinders one after the other with fuel.

It is known that the noise behaviour of the engine can be substantially improved by a small quantity of fuel injected into the cylinder shortly before the actual main injection. This injection is known as preliminary injection or as pilot injection,

The cause of noise output by the engine is that the very steep pressure rise, which occurs during the ignition of the fuel in the cylinder and which is responsible for the knocking noise of diesel engines, is flattened.

The injection quantity which is required for the preliminary injection and is very small by comparison with the main injection cannot be admetered with sufficient accuracy due to different interference magnitudes which are not detectable or cannot be evaluated in terms of measurement technique.

In the case of an injection system which is controlled by a valve with electromagnetic or piezo-electric actuation and in which an electrically drivable magnetic or piezo-electric actuator controls the pressure build-up of the fuel and the pressure-controlled opening of the injection valve occurs as a consequence thereof, the main interference magnitudes are for example a first dead time between the beginning of the electrical control signal and the opening of the injection valve needle and a second dead time between the end of the electrical signal and the closing of the injection valve needle.

These magnitudes are illustrated in Figs. 2a) to c). The drive signals U for an injection cycle with preliminary injection and main injection are entered in Fig. 2a). The prelimimary injection drive signal has the duration ASDV. The course of the pressure P in the injection nozzle is entered in Fig. 2b) and the stroke H of the injection valve needle is entered in Fig. 2c). These signals are entered as a function of time t or as a function of degrees of crankshaft angle.

The first dead time t_{01} elapses between the drive-on instant A, at which the signal U passes over from its low to a high level, to the instant SB1, at which the injection valve needle moves. The second dead time t_{02} elapses between the drive-off instant B and the injection end, at which the injection valve needle is again situated in its initial position.

After the drive-on instant A, a pressure builds up as a function of time in the injection nozzle. This rise takes place during the dead time t_{01}. When the pressure reaches an envisaged value, the injection needle lifts off and injection begins.

After the instant B, at which the drive-on signal U has again fallen to zero, the fuel pressure in the injection nozzle falls as a function of time. At the same time, the injection valve needle returns to its original position.

The fuel injection takes place in the time span in which the injection valve needle is out of its rest position. The injection duration t_i of the preliminary injection can be represented by the relationship:

$$t_1 = ASDV = (t_{01} - t_{02}).$$

The expression $(t_{01} - t_{02})$ represents the effective dead time. It is denoted as dead time in the following. This value fluctuates between the individual cylinders, these fluctuations being due to tolerances of the fuel injection system consisting of the injection valve, the injection duct and the electromagnetic valve. Moreover, this value changes in the course of the operating time.

The two dead times can be greater than the actual injection time t_i, particularly for the preliminary injection. Small percentage changes in these dead times therefore cause large percentage changes in the injection time and thereby in the quantity of fuel injected. These dead times can be different or change in dependence on operating time due to inter alia the nozzle opening pressure dependent on the particular nozzle, the temperature-dependent viscosity of the fuel or tolerances of the electrically operated actuator.

It is thus desirable to ascertain the dead time as accurately as possible, either continuously or at certain time intervals, whereby the quantity of fuel injected in preliminary injection can be admetered substantially more accurately.

In Fig. 3, the course of the pressure P in a cylinder and the stroke NH of the electromagnetic valve needle are entered as a function of time or of crankshaft angle. The pressure course without preliminary injection is represented by a solid line and the course with preliminary injection by a dashed line. As can be seen, the preliminary injection causes a flattening of the steep pressure rise of the cylinder pressure after ignition of the fuel.

The frequency spectrum of the pressure course is entered in Fig. 4. The frequency of camshaft rotation is denoted by f_N, the frequency of crankshaft rotation by f_K, three times the camshaft rotation by $3f_N$ and twice the crankshaft rotation by $2f_K$. The envelope of the frequency spectrum when no preliminary injection takes place is represented by a solid line. The conditions with

preliminary injections are illustrated by dashed lines. As is evident, the preliminary injection has the effect of a lowering of the amplitude of the high frequency components. By reference to this reduction in the amplitude of the high frequencies in the pressure signal, it can be ascertained that preliminary injection has taken place.

For ascertaining the dead time, the drive signal duration ASDV is increased continuously starting from a short duration ASDV for which no injection takes place. At the same time, the signal duration is amplitude-modulated with a very small amplitude. The duration is preferably modulated with an amplitude which corresponds to 0.1 degrees of crankshaft angle. The modulation frequency f_M related to one cylinder is given by the following formula, applicable to a four-stroke engine:

$$f_M = 0.5 * N/60 * X.$$

In this case, X is a factor which can preferably assume the values 1/2, 1/3, 1/4, 1/5, 1/6, .. 1/K, wherein K is a natural number greater than 2. N is crankshaft speed in $\min^{-1}$. For a two-stroke engine, the formula is

$$f_M = N/60 * X.$$

If X = 1/2, this means that, for example, each second duration ASDV is increased by a time which corresponds to 0.1 degrees of crankshaft angle and that each other duration is reduced by 0.1

degrees of crankshaft angle. This is illustrated in Fig. 5a). Here, durations of 12.7 and 12.9 degrees of crankshaft angle KW are provided in alternation for the preliminary injection.

The duration at which preliminary injection occurs is represented by a dashed line. As illustrated in Fig. 5a), the drive signal duration lies clearly below the duration necessary for the preliminary injection. Subsequently, the mean duration is increased until preliminary injection takes place.

In Fig. 5b), the mean duration is equal to the sought dead time at which preliminary injection occurs. When the actual duration is 0.1 degrees of crankshaft angle above this mean duration, a preliminary injection takes place, whereas when it is under the mean duration no preliminary injection takes place.

In Fig. 5c), the mean duration is so chosen that preliminary injection takes place even for the reduced duration.

In the case of the control according to Figs. 5b) and 5c), the high frequency components of the spectrum are now amplitude-modulated at exactly the modulation frequency f_M, as illustrated in Fig. 4. This means that switching is carried out to and fro, according to Fig. 4, between different envelopes in the spectrum at the amplitude modulation frequency f_M. In the case of the control according to Fig. 5a), such a modulation of the pressure signal P does not occur.

This modulation frequency f_M can be filtered out of the pressure course. This is easily possible, particularly since the frequency f_M is known. The mean duration is now set by means of a

simple regulating loop so that the modulation frequency f_M is just detectable. In this case, the mean duration corresponds to the sought dead time.

Equipment for detection of the modulation frequency f_M is illustrated, by way of example, in Fig. 6. The equipment comprises a cylinder pressure sensor 600, the output signal of which is applied to a band-pass filter 610. The output signal of this filter is fed by way of a demodulator 620 to a second band-pass filter 630.

The higher frequency components are filtered out of the signal from the cylinder pressure sensor 600 by the first band-pass filter 610. The limit frequency of the first band-pass filter is, for example, between 5 and 100 times the crankshaft rotation f_K. The modulation signal is prepared in the following demodulator 620. The second band-pass filter 630 has a narrow bandwidth and its centre frequency lies at the modulation frequency f_M. Consequently, a signal is present at the output of the second filter only when a preliminary injection takes place.

The particular frequencies for the first band-pass filter as shown in Fig. 6 represent guide values and are to be considered only as examples.

This equipment for the detection of the modulation frequency f_M can be in the form of an analog circuit or part of a program of a microprocessor.

In place of the cylinder pressure sensor there can be used a sensor for solid-borne sound, an acceleration sensor at the engine or a sound pick-up in the form of a microphone. It is sufficient to provide one sensor for all cylinders. For example, a knock sensor is suitable as body-borne sound sensor.

It is particularly advantageous if the main injection quantity is reduced each time by the actual or averaged preliminary injection quantity in order that the operating point of the engine can be kept constant.

A method exemplifying the invention will now be explained briefly by reference to the flow diagram of Fig. 7. It is recognised in a first step 700 that the correction values for the drive signal duration are to be ascertained subsequently. A mean duration ASDV M for the preliminary injection is then preset in a step 710. The vale of this duration is chosen so that, with certainty, no preliminary injection will occur. Subsequently, the duration is amplitude-modulated in a step 720. The output signal of a sensor, such as knock sensor, is then filtered in a step 730. With the aid of the filtered signal, an interrogation step 740 recognises whether or not preliminary injection has occurred. If this is not the case, the mean duration ASDV M is increased by a small value E in a step 750. Subsequently, the step 720 is repeated.

When the interrogation step 740 recognises that a preliminary injection has just occurred, the dead time is computed starting out from the mean duration ASDV M in a step 760.

Compensating signals for drive pulses, which cause the injection, can be formed, starting from the dead time or the mean drive signal duration, and stored. Preferably, these compensating signals are determined either once at the end of the engine production or at certain intervals. Thus, for example, this

determination could be performed within the scope of engine servicing at fixed intervals of time, at certain mileages or in the presence of certain operating states, for example following a starting operation.

It is also possible to use, in place of the sensors mentioned, so far, engine torque sensors or engine speed sensors. In this case, the main injected quantity may not be reduced or only by the mean preliminarily injected quantity. In particular, a modulation of engine torque or speed takes place in the case of a drive control according to Figs. 5b) and 5c), respectively. In the case of the control according to Fig. 5a), no modulation of torque or speed occurs. The modulation frequency in the engine torque or speed course can be detected by means of a band-pass filter with a frequency f_M equal to 1/2 * N/60 * X for a four stroke engine or to N/60 * X for a two stroke engine. If this modulation of the speed signal or torque signal is detected, the signal duration must be greater than the sought dead time.

The dead times ascertained by this method can also be utilised in correction of the signal duration for the main injection.

CLAIMS

1. A method of determing a control parameter for a fuel injection system providing preliminary and main injection in an engine by way of an electrically actuable valve, the method comprising the step of determining a dead time of the system by modulating the duration of a drive signal for the valve in time at a defined frequency and amplitude, increasing the duration starting from a value range too low for preliminary injection to occur, and detecting, on the basis of a sensor signal indicative of at least one magnitude influenced by injection, first occurrence of preliminary injection in response to the increase in the duration.

2. A method as claimed in claim 1, wherein the signal is indicative of at least one of pressure, sound, acceleration, torque and rotational speed.

3. A method as claimed in claim 1 or claim 2, wherein the occurrence of preliminary injection is recognised in response to signal output at filter means having the sensor signal as an input.

4. A method as claimed in any one of the preceding claims, comprising the step of setting the modulation frequency in dependence on engine speed.

5. A method as claimed in claim 3, the filter means comprising a band-pass filter having a lower limit frequency substantially higher than the engine speed.

6. A method as claimed in claim 3, the filter means comprising a band-pass filter having a centre frequency corresponding with the modulation frequency.

7. A method as claimed in any one of the preceding claims, comprising the further steps of determining a compensating signal for the drive signal in dependence on the determined dead time and storing the compensating signal.

8. A method as claimed in claim 7, wherein the step of determining the compensating signal is carried out once after fitment of the system to the engine.

9. A method as claimed in claim 1, wherein the step of determining the compensating signal is carried out at predetermined intervals.

10. A method as claimed in claim 1 and substantially as hereinbefore described with reference to the accompanying drawings.

11. Control means for a fuel injection system providing preliminary and main injection in an engine by way of an electrically actuable valve, the control means comprising means for determining a dead time of the system by modulating the duration of a drive signal for the valve in the time at a defined frequency and amplitude, increasing the duration starting from a value range too

low for preliminary injection to occur, and detecting, on the basis of a sensor signal indicative of at least one magnitude influenced by injection, first occurrence of preliminary injection in response to the increase in the duration.

12. Control means as claimed in claim 11, wherein the valve is a component of a high-pressure fuel pump.

13. Control means substantially as hereinbefore described with reference to the accompanying drawings.

Examiner's report to the Comptroller under Section 17 (The Search report) - 17 -

GB 9407041.4

Relevant Technical Fields	
(i) UK Cl (Ed.M) G3N (GK1, GK2)	Search Examiner MR D A SIMPSON
(ii) Int Cl (Ed.5) F02D (41/38, 41/40)	Date of completion of Search 30 JUNE 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) WPI	Documents considered relevant following a search in respect of Claims :- 1 TO 13

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
X	US 5070836 (ROBERT BOSCH) column 3 line 40 to 68	1, 2, 7, 8, 9, 11, 12

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